



# Airborne Satcom Terminal Research at NASA Glenn

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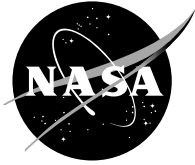
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Space Administration

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# **Airborne Satcom Terminal Research at NASA Glenn**

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## **Abstract:**

*NASA Glenn has constructed an airborne Ku-band satellite terminal, which provides wideband full-duplex ground-aircraft communications. The terminal makes use of novel electronically-steered phased array antennas and provides IP connectivity to and from the ground.*

*The satcom terminal communications equipment may be easily changed whenever a new configuration is required, enhancing the terminal's versatility.*

## **I. Background:**

NASA's Aviation Safety, and Aviation Capacity Programs are federally-funded initiatives designed to utilize technology to improve the nation's air transportation system.

It is well accepted that air travel is one of the safest modes of transportation. The aviation community has enjoyed one of the best safety records of any form of transportation. Although the aviation accident rate is extremely low, the projected growth in air travel through the early part of this century poses a serious safety challenge to the aviation community. The challenge is that the number of aviation accidents will significantly increase if the accident rate does not decline. On February 12, 1997 President Clinton called for an 80% reduction in the rate of fatal accidents within 10 years and a 90% reduction within 20 years. In response, NASA has initiated the *Aviation Safety Program (AvSP)* in partnership with industry and other government agencies to address the President's National Aviation Safety Goal. The Aviation Safety Program is a Level I program of NASA's Office of Aerospace Technology (OAT).

In 1997, shortly after the President announced the National Aviation Safety Goal, the Aeronautics Safety Investment Strategy Team (ASIST) defined many of the technical objectives of what was to become the AvSP. The team recognized that weather was a major contributing factor in aviation incidents and accidents. A key recommendation of the ASIST activity was for a significant effort in weather accident prevention. As a result, weather accident prevention (WxAP) has been incorporated as a Level II project of the AvSP. Furthermore, the ASIST weather team produced a prioritized list of investment areas under weather accident prevention. Weather data dissemination was considered to be the most critical and highest ranked priority on the list. As a result, the AvSP, under the WxAP project, created the aviation Weather Information Communications (WINCOMM) and the Aviation Weather Information (AWIN) Level III elements. The combined objective of the WINCOMM and AWIN elements are to develop technologies that will provide accurate, timely and intuitive information to pilots,

dispatchers, and air traffic controllers to enable the detection and avoidance of atmospheric hazards. The WINCOMM element in particular addresses the communications specific issues associated with the dissemination of weather data. The AWIN element specifically addresses operator support and enhanced weather product research issues. The WINCOMM and AWIN elements are highly integrated due their inherent synergy.

NASA Glenn's involvement in the WINCOMM and AWIN programs is primarily in the area of communications. Glenn has a history of research and development in the area of satellite communications. They have been responsible for several major innovative satellite programs, including CTS (Communications Technology Satellite) and ACTS (Advanced Communications Technology Satellite).

NASA Glenn has constructed a satcom terminal (known as the *Aero-Mobile satcom terminal*) to serve as a test bed for investigating and demonstrating new aviation communications technology--primarily satellite communications. The premise is that more reliable, wider bandwidth communications can improve both airspace capacity and safety through increased awareness of position, obstacles, weather, etc. The terminal's electronics can be easily changed whenever a new communications configuration is required. A description of the terminal is included the sections ahead.

## **II. Terminal**

The Aero-Mobile satcom terminal was designed to be installed in either an aircraft or a ground vehicle (in this case a large van). The ground vehicle provides an opportunity to test the system without the expense or logistical burden of flight testing.

A great deal of the integration and initial testing did not require the terminal to be in flight, so the van proved to be a cost-effective alternative. The van is equipped with a laser ring-gyro and a Global Positioning Satellite (GPS) receiver which, when integrated with a computer, provides the required navigational data in the same format as the aircraft data system.

The terminal uses commercial Ku-band satellites and provides full duplex connectivity to a fixed station (located at NASA Glenn). The airborne (or mobile) hosts (computers) are connected into the Glenn network, and appear as local machines.

The terminal design is based around earlier fixed and shipboard reflector antenna terminals built at NASA Glenn, but incorporates a set of electronically-steered phased-array antennas (receive and transmit). These were purchased from the Boeing Company.

The phased-array antennas are configured for frequency, polarization and longitude of the satellite to be used. The antenna control system takes the position data and platform attitude data and calculates the correct pointing angle for both the transmit and receive arrays. The platform position and attitude data are derived from an ARINC

429 interface to the laser gyro/GPS system on the van, or directly into the aircraft INS (*inertial navigation system*) system (on a ARINC 429-equipped aircraft).

The received downlink RF signal is downconverted and directed to a commercial satellite mode for demodulation. The demodulated data stream is then routed to a Cisco router, which serves as a gateway for hosts connected to the terminal.

An earlier version of the terminal used a Sun workstation as a gateway. Although the Sun workstation provided a much more flexible interface, the Cisco router is a simpler and more easily-configurable solution, and can also operate at higher data rates.

Similarly, the uplink data stream from airborne hosts is routed through the Cisco router to a semi-custom spread spectrum modem, into an upconverter and then through the transmit array.

The spread spectrum modulation is used on the airborne uplink to mitigate adjacent satellite interference due to the wide beamwidth of the transmit array.



*Figure 1: Aero-Mobile van and NASA Glenn fixed station*



Figure 2: Phased-Array antennas mounted on Aero-Mobile Van

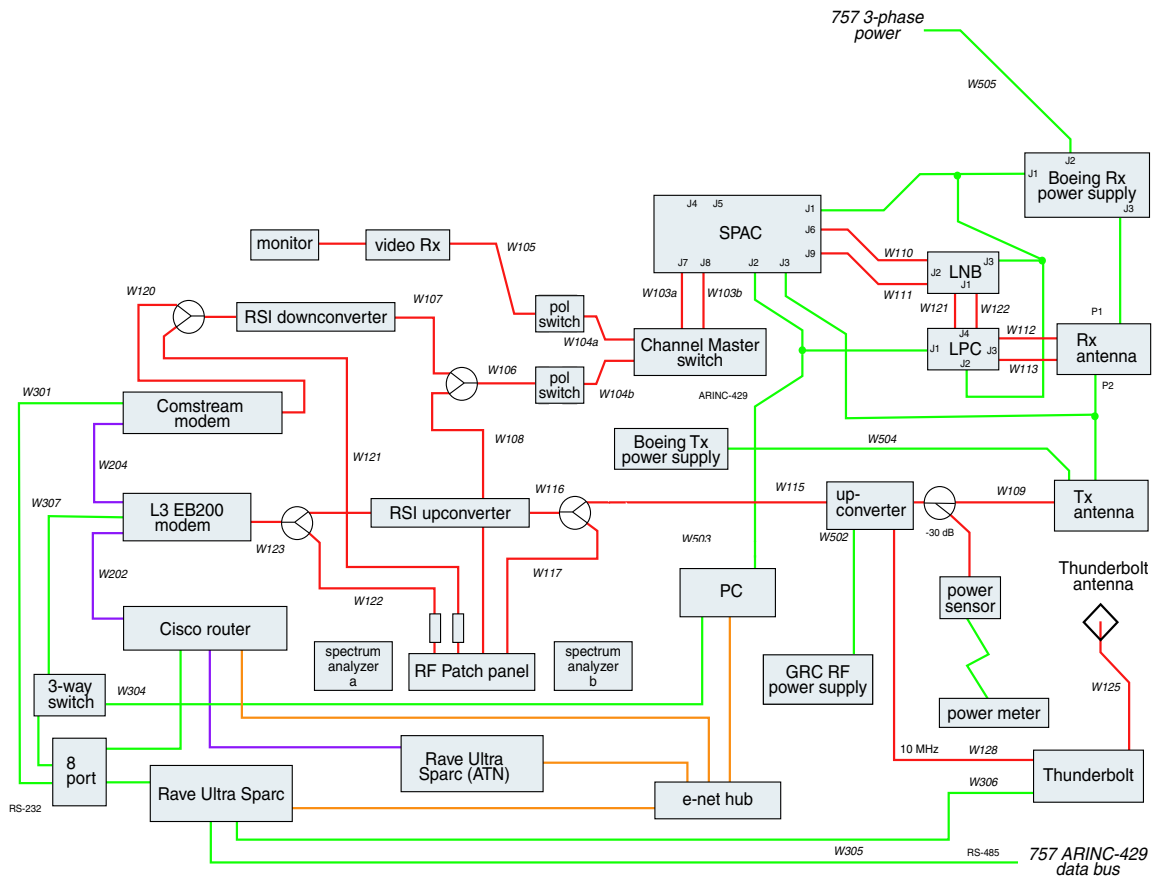


Figure 3: Block diagram of airborne terminal



### III. General Performance Parameters

The general performance parameters of the terminal are:

#### *Ku-band uplink*

frequency: 14.0 – 14.5 GHz

number of elements in the Tx array: 254

EIRP: 36 dBW

modulation: QPSK with direct-sequence spread spectrum, up to 512 kb/s

error-correcting coding: 1/2 rate convolutional

spreading: to 10 MHz

#### *Ku-band downlink*

frequency: 11.75 – 12.25 GHz

number of elements in the Rx array: 1536

G/T: 34 dB/K

modulation: QPSK, up to 4 Mb/s

error-correcting coding: 1/2 rate convolutional, rate 235/255 Reed-Solomon

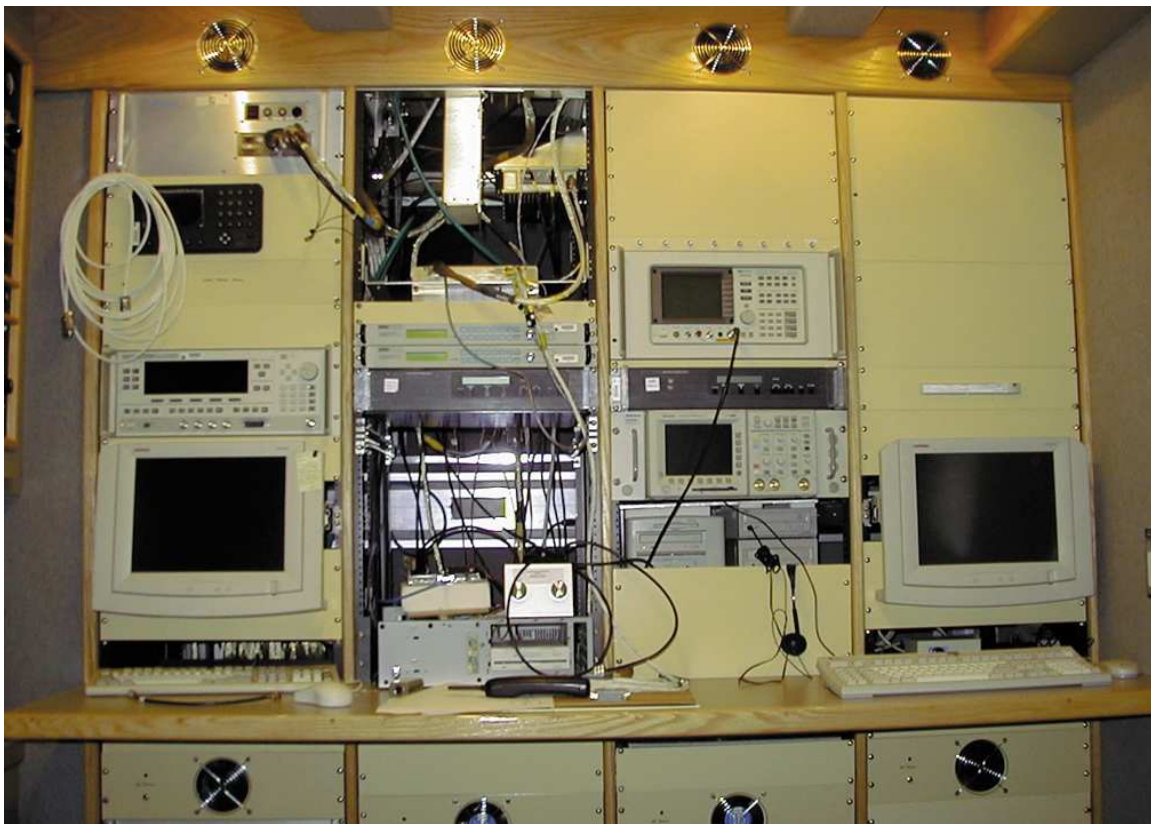


Figure 4: Photo of terminal equipment installed in Aero-Mobile van

#### IV. Data and networking

The terminal sends and receives internet protocol (IP) data, providing an extension of the NASA Glenn local network.

The gateway device (the Cisco router) is connected through the satellite link and to a complimentary device at the fixed station. The gateway at the fixed station is connected to the Glenn local network. This places the airborne gateway and any airborne hosts directly on the NASA Glenn network. Each host has a unique IP address.

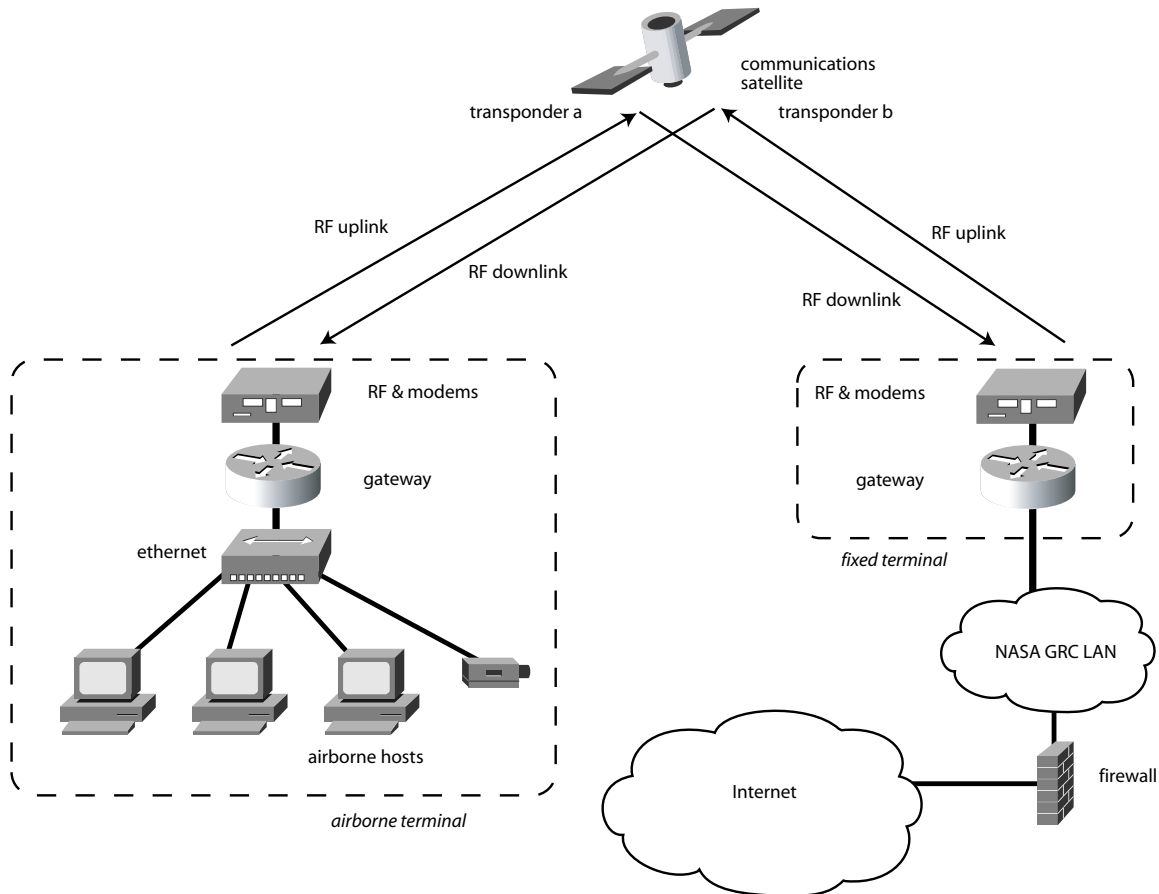


Figure 5: Network diagram

#### V. Boeing Antennas

The receive antenna was initially developed by Boeing for satellite TV reception in business jets, from previous Government and internal research. The transmit antenna was jointly developed between Boeing and NASA Glenn (formerly NASA Lewis). These antennas are ideal for aircraft use, with very low profile and very fast pointing response.

The two Boeing antennas were a result of both SBIR and DoD/NASA development contracts. The Air Force's Rome Laboratories had a development contract with Boeing

for large phased array antenna design, with a subarray module as one of the deliverables. NASA requested that Rome Labs add a task to the original contract to provide a nominal 16 element receive array for NASA experiments. The receive array was to be a similar size as an older Texas Instruments transmit antenna—to result in similar performance. Both NASA and the Air Force supported this effort and a small antenna was ordered. While the original antenna design used a waveguide feed, to minimize cost and complexity, this antenna was space fed and had 23 dielectric loaded elements arranged in five rows. This antenna was one of three antennas that were flown on NASA Glenn's LearJet supporting the Aero-X experiment with the ACTS satellite <sup>(1)</sup>

Boeing later redesigned the radiating modules to lower the antenna height. This antenna became their Ku-band receive antenna which was used as a business-jet television receive antenna.

NASA Glenn initiated a development contract, with Boeing, for a 254 element Ku-band transmit antenna through the US Navy's SPAWAR. The transmit antenna had the same radiating element design as the current receive antenna.

As the transmit antenna is physically smaller than the receive, an adapter plate was designed to permit the transmit antenna to be installed in a second receive antenna mounting frame attached to the aircraft's fuselage.

Since most of the current aircraft band communication links are both narrowband and utilized to capacity, a test utilizing a wide band satellite link would be performed. The two Ku-band antennas would allow wide band link testing through a satellite to verify the system operation. Operational satellites would probably operate at different frequencies, but the link characteristics and delays would be similar.



*Figure 5: Phased-Array antennas mounted on NASA Dryden DC-8*



*Figure 6: Front of NASA Dryden DC-8 showing receive antenna*



Figure 7: Tail of NASA Dryden DC-8 showing transmit antenna

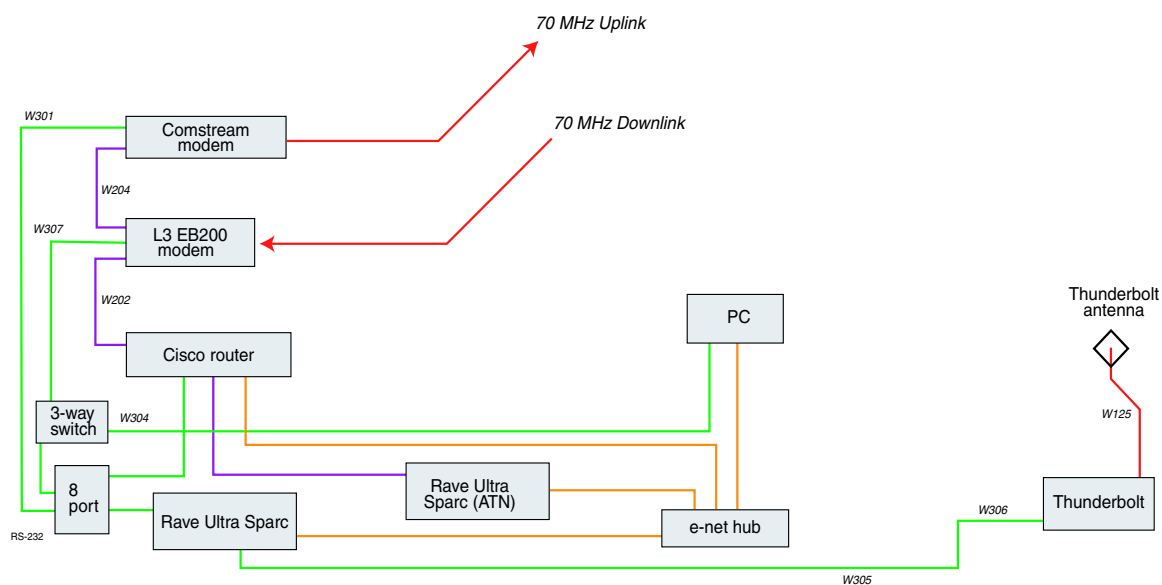


Figure 8: Block diagram of fixed terminal

## VI. Experiments

The terminal has been used in the mobile environment since the spring of 2000, and was flown on the NASA Dryden DC-8 in December of 2000. The terminal was later

installed on the NASA Langley 757 “ARIES” (Airborne Research Integrated Experiment System).

### **A. IP applications tested**

So far, most of the applications tested through the system have used IP: telnet, ftp, ssh, http, etc. These all function as they would on a terrestrial network (aside from a 1/2 second transit delay). Two ATN (*Aeronautical Telecommunication Network*)-based demo applications from Eurocontrol have also been tested.

In order to get terrestrial-like performance out of the satellite link, the bit error rate must be extremely low, typically less than  $10^{-8}$ . With error-correcting coding, this performance is easily achieved

Typical performance is  $BER \leq 10^{-8}$ , with an  $E_b/N_0$  of about 15 dB\*Hz, for both uplink and downlink.

### **B. Mobile tests**

The first tests were performed in AATT Aero-Mobile van. In addition to RF performance measurements, the standard IP suite of test was performed. The data is included in Appendix 1.

### **C. AeroSAPIENT tests**

In December of 2000, the terminal was flown on the NASA Dryden DC-8 Airborne Sciences Laboratory. The system supported a sensor-data experiment, providing connection to a ground internet.

Dryden also tested a Java-based measurement network and data transport middleware concept called the Ring Buffered Network Bus, or RBNB. The RBNB provided simultaneous onboard data archival and online distribution of multiple flight data streams over the satellite link to a nationwide network of destinations on the ground. Some of these data streams were encrypted with public key infrastructure (PKI) technology.

This experiment successfully demonstrated real-time data link technology to move and distribute unique and distinct flight data to multiple sites in real time while addressing multilevel priorities in a secure, high-integrity data-sharing environment.

This mission was a collaborative effort using in-flight network communications technology, enabling various simultaneous applications to be conducted at bidirectional rates 100 times greater than what is operational in today's National Airspace System.

In addition to constructing a network architecture that included a mobile platform and simultaneous bidirectional applications, the evaluation of the physical electrical

interconnect and the network performance was of particular interest in understanding a high-integrity communications environment. Because this mission was the first NASA flight of the prototype Ku-band antenna system, the antennas were characterized in a variety of flight profiles that included different combinations of roll, pitch, and heading with regard to the geostationary satellite.

The experimental link performed extremely well, yielding data transfers of approximately 2.1 Mbits/sec onto the aircraft, and 256 kbits/sec from the aircraft to the ground network that extended across the Nation. The data rates were limited by the installed firmware on the various modems used in the network, and could be increased by upgrading to the latest modem firmware revisions. Extreme flight profiles (e.g., a 45° change in roll coupled with a 50° change in heading) were purposely flown to determine the threshold of sustaining the communication link. This also provided some insight into the relationship between the antenna system performance and the network recovery, during a particular flight profile or system event.

A comprehensive report is available in reference <sup>(2)</sup>.

#### **D. NASA Langley 757**

In early 2002, the terminal was installed on the NASA Langley 757 “ARIES”, in support of NASA's WinComm project. It was to be used to transfer realtime weather data to and from the 757.

The satellite link provided realtime weather data from Rockwell Collins. The data was used by the airborne researchers to guide the aircraft into areas of convective turbulence, in order to calibrate/quantify/check out an airborne weather radar system.

The system performance was nominal during ground testing and the early flights. The experimenters on the 757 were satisfied with the data quality. Unfortunately, later in the flight campaign, the data quality degraded to the point of being unusable. The problem was traced to a malfunctioning Low Noise Block downconverter (LNB). The LNB was eventually replaced after the flight campaign was concluded.





Figure 9: NASA LaRC "ARIES" 757 with antennas installed along top of fuselage

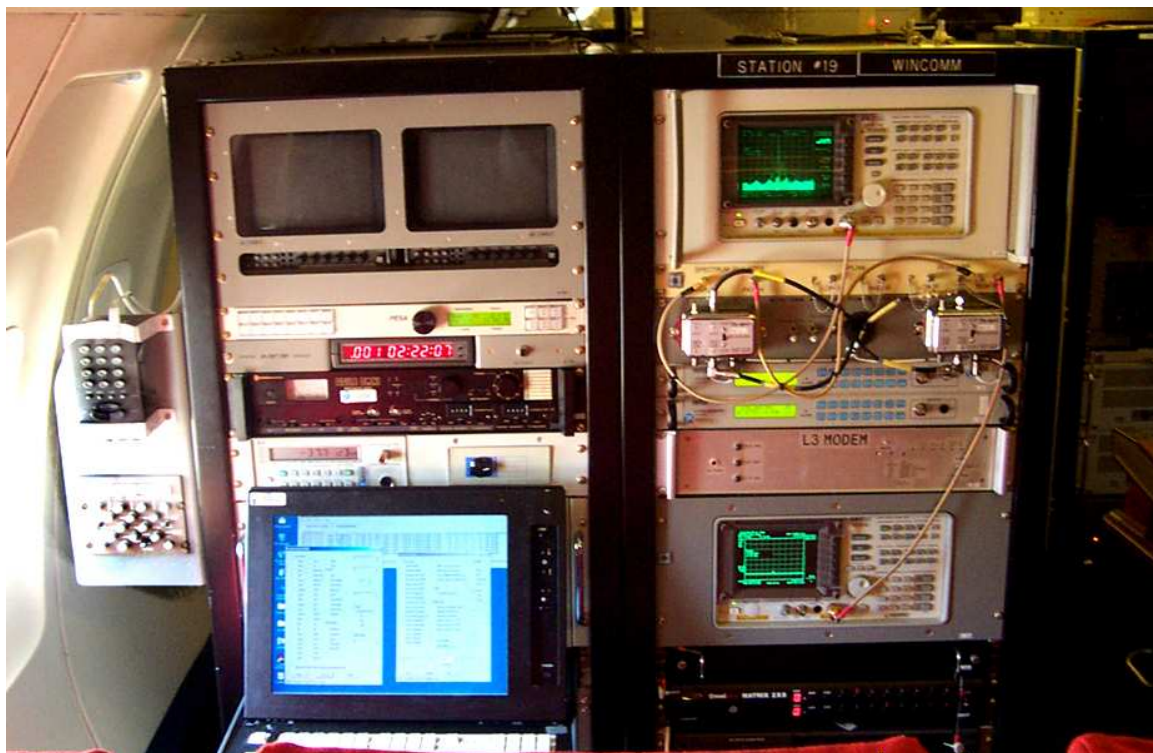


Figure 10: Terminal equipment rack inside NASA LaRC 757



## VII. Conclusions and Observations:

1) In the mobile environment, and with a *good* INS system (like our laser gyro) we can make the Boeing antennas work pretty well--both at rest and in motion. Since they don't do any real tracking for pointing, the occasional bridge doesn't present much of a problem to recovery of the antenna pointing.

That is not the case however for polarization. Polarization tracking is accomplished with a servo loop, so the fades from obstructions have been known to cause 180 degree flips in the antenna polarization--requiring manual intervention. The loop seems to be slow enough however, that brief fades do not seem to be a problem.

2) With the 8 m antenna of the fixed station, we were able to transmit 2.048 Mb/s from the fixed station to the mobile (forward link) with zero errors. We had almost 6 dB of margin. In the initial system, we were constrained by modem interface cards to about 2 Mb/s. Later, these were replaced with higher-speed interfaces which allowed us to transmit up to 4 Mb/s--although we typically held this to 2 Mb/s in order to maintain some link margin.

On the reverse link (mobile-to-fixed) we were able to transmit 256 kb/s with no errors. Again, we had about 6 dB of margin. We initially had trouble with the L3 modem at this rate, but this was later corrected and we were able to transmit data at 512 kb/s. Again, we sometimes backed this down to a lower rate (typically 256 kb/s) in order to have some link margin.

The satellite we used (AMC-2--formerly GE-2) has both high EIRP and G/T, giving very good performance with a small-aperture satellite terminal. The performance would not necessarily be as good with an older satellite. A typical estimated link budget is included in Appendix 5.

3) We were able to establish IP connectivity between any host in the van and any host in the GRC network. We were able to run the usual IP applications (http, ftp, telnet, ssh) with no problems related to routing.

The only minor problem was the non-optimum performance of the ftp. This is due to the large bandwidth-delay product of the 2 Mb/s link and the 500 ms GEO delay, and non-optimized window sizes in the ftp application.

4) The IP phones worked very well, providing there is enough bandwidth available.

**References:**

- (1) Zakrajsek, Robert J., *Advanced Antenna Technology for Aeronautical Communications*--Space Communication Technology Link vol 2, no. , April 1999 (NASA Glenn Research Center, Cleveland Ohio).
- (2)) Brooks, David E., Romaniak, Gregory W., Frantz, Brian D., *AeroSAPIENT Final Report: DC-8 Flight Experiment: November through December 2000 for RSIS Task A6.1 Task Requirement*--July 11, 2001 (NASA Glenn Research Center, Cleveland Ohio).

## **Appendix 1: Test Descriptions**

### 1) $C/N_0$

This measurement gives a qualitative assessment of the RF performance, without considering the subsequent stages.

A pure carrier (at the same power output as the modulated signal) is transmitted from each station to the receiving end. The carrier power is measured at the first IF (L-band) using a spectrum analyzer with its resolution bandwidth set fairly wide (about 3 MHz). This value is recorded as "C", in dBm.

While the carrier is still present, the spectrum analyzers noise measurement function ("noise marker") is activated. This provides an approximate measurement of noise spectral density. The marker is moved around the carrier in about a 5 MHz span, and an average is taken of several values. This averaged value is recorded as " $N_0$ ", in dBm/Hz.

The carrier-to-noise density ratio ( $C/N_0$ ) is simply the difference, expressed in dB\*Hz.

### 2) $E_b/N_0$

The energy per bit-to-noise density ratio  $E_b/N_0$  provides a measurement of signal quality as seen by the demodulators.

The Comstream CM-701 modems (used in the fixed-to-mobile link) provide a direct display of  $E_b/N_0$ . The L3 EB200 modems (used in the mobile-to-fixed link), provide no such measurement, so the  $E_b/N_0$  is calculated by subtracting  $10 \cdot \log$  of the data rate.

For example, with a  $C/N_0$  of 70 dB\*Hz and a data rate of 256 kb/s, the  $E_b/N_0$  will be  $70 - 10 \cdot \log(256,000) = 70 - 54 = 16$  dB.

The calculated number for the other modem is usually very close to that displayed.

### 3) network tests

The network tests verify connectivity and IP services between hosts. The tests were performed both between the mobile and fixed gateway hosts and between hosts connected to the gateway machines.

The following hosts combinations were tested:

mobile gateway to fixed gateway  
fixed gateway to mobile gateway

host attached to the fixed gateway to the mobile gateway  
host attached to the mobile gateway to the fixed gateway  
host attached to the fixed gateway to host attached to the mobile gateway  
host attached to the mobile gateway to host attached to the fixed gateway

### 3.1) ping

An IP "ping" was performed between hosts and the success and round trip time were observed and recorded.

Typical ping times were about 520 msec. This is pretty standard for a geosynchronous satellite link, where the length of each path is approximately 125 msec. The complete ping path requires four hops (to the satellite, down to the first ground station, back to the satellite and back to the other station).

All pings were successful.

### 3.2) ssh

Secure-Shell (SSH) logins were performed in the same combinations. These were all successful.

### 3.3) ttcp

ttcp is a performance measurement tool for TCP links. It provides an accurate measurement of real data throughput rate--which can be highly dependent upon the delay\*bandwidth product. With the long geosynchronous satellite delay, this becomes an issue.

With the van fixed, typical throughput rates were 1980 kb/s from the fixed to the mobile, and 240 kb/s from the mobile to the fixed. Compare this to the modem rates of 2048 and 256 kb/s respectively.

Results for the mobile experiment were slightly less--due to outages caused by underpasses. These rates were recorded from 660 to 1320 kb/s for the fixed-to-mobile link and 210 kb/s for the mobile-to-fixed link.

### 3.4) ftp

File transfer were performed using standard ftp. This was done simply to verify functionality, as the ftp parameters were not tuned to compensate for the large bandwidth\*delay product. Although the file transfer were successful, the speed was not impressive. Also, the ftp application does not correctly report the true transfer rate. We know this because the application reported rates HIGHER than the data rate for mobile-to-fixed transfers.

### 3.5) IP Phones

A set of E-tel IP phones was used with the system to demonstrate voice-over-IP. The quality in all cases was okay to good. These phones use an adaptive codec, so generally, the sound quality is better when there is more bandwidth available. With other traffic on both links, the higher-speed fixed-to-mobile link sounds better than the mobile-to-fixed. With both links clear, the sound quality is comparable on both ends.



## ***Appendix 2: Aero-mobile Van Test Results***

The concise results follow below. More detailed logs and tcp dumps available.

### **Stationary Test:**

Wednesday, February 21, 2001  
12:55 PM

Fixed test at GRC, bldg 311  
weather: CLEAR  
satellite: GE-2 85° W

mobile-to-fixed link  
xpndr K16H  
uplink 14320 MHz  
downlink 12020 MHz H

fixed-to-mobile link  
xpndr K14H  
uplink 14280 MHz  
downlink 11980 MHz H

#### *f-to-m*

uplink pwr: 10 W (at the fixed station)  
tx pol offset: 125° (on the van)  
rate: 2048 kb/s  
(measured at the van)  
C: -50.2  
 $N_0$ : -130  
 $C/N_0 = 79.8$   
BER: 0  
 $E_b/N_0$ : 15.7

#### *m-to-f*

uplink pwr: 1.24 (in the van)  
rate: 256 kb/s  
(measured at the fixed station)  
C: -30.0  
 $N_0$ : -100  
 $C/N_0 = 70$   
  
BER: 0  
 $E_b/N_0$ : 16 (calculated)

1:14 PM

#### 4.1 m-to-f gateway

("fixed-gw" is main host and gateway at the fixed station,  
"mobile-gw" is the gateway on the van)

ping fixed-gw: 520 ms

ssh fixed-gw YES

ttcp f-m: 1980 kb/s avg rate

ttcp m-f: 240 kb/s avg rate

ftp from fixed-gw /home/aatt/ntp.tar

4030464 bytes 83 sec 47.50 kB/s = 380 kb/s

(we know that is slow compared to the link data rate, but we  
used standard ftp, without the TCP parameters optimized)

ftp from mobile-gw /home/aatt/ntp.tar

4030464 bytes 110 sec 36.2 kB/s = 289.5 kb/s

(we know this is somewhat high, but that is what ftp reported)

IP phones: quality okay/good

#### 4.2 m-to-f network (portal)

("portal" is a remote host on the GRC network)

ping portal: 525 ms

ssh portal: YES

ttcp f-m: 1810 kb/s avg rate

ttcp m-f: 240 kb/s avg rate

#### 4.3 network to network

("mobile\_pc" is a remote host in the van, connected to the  
gateway via ethernet)

ping portal to mobile\_pc 522 ms

ping mobile\_pc to portal 510 ms

mobile\_pc connected to van hub (139.88.12.31)

3:04 PM

mobile uplink pwr: 1.24 (readjusted)

(we have noticed that the van uplink power drifts as much as 2 or 3 dB throughout the day--we  
think it's thermal)

#### **Mobile Test:**

(same comments on each item apply AND we had to travel under bridges occasionally)

Thursday, February 22, 2001



8:56 AM

Mobile test  
weather: OVERCAST  
GE-2 85° W

mobile-to-fixed  
K16H  
uplink 14320 MHz  
downlink 12020 MHz H

fixed-to-mobile  
K14H  
uplink 14280 MHz  
downlink 11980 MHz H

*f-to-m*

uplink pwr: 9 W  
tx pol offset: 125°  
rate: 2048 kb/s  
C: -42.0  
 $N_0$ : -129.5  
 $C/N_0 = 87.5$

BER: 0  
 $E_b/N_0$ : 15.7

*m-to-f*

uplink pwr: 1.24  
rate: 256 kb/s  
C: -28.5  
 $N_0$ : -99.0  
 $C/N_0 = 70.5$

BER: 0  
 $E_b/N_0$ : 16.5 (calculated)

9:37 AM

4.1 m-to-f gateway  
ping fixed-gw: 520 ms  
ssh fixed-gw YES  
ttcp f-m: 1320 kb/s  
ttcp m-f: 210 kb/s avg

ftp from fixed-gw /home/aatt/ntp.tar

4030464 bytes 100 sec 39.3 kB/s = 314.4 kb/s

ftp from mobile-gw /home/aatt/ntp.tar

4030464 bytes 110 sec 34.3 kB/s = 274.4 kb/s

IP phones: quality okay/good

4.2 m-to-f network (portal)

ping portal: 520 ms

ssh portal: YES

ttcp f-m: 660 kb/s

ttcp m-f: 210 kb/s

4.3 network to network

ping portal to mobile\_pc 524 ms

ping mobile\_pc to portal 580 ms

mobile\_pc connected to van hub (139.88.12.31)

11:01 AM

mobile uplink pwr: 1.40 (readjusted)

11:25 AM

f-to-m

uplink pwr: 9 W

tx pol offset: 125°

rate: 2048 kb/s

C: -51.0

No: -129.5

C/No = 78.5

BER: 0

$E_b/N_0$ : 14.8

m-to-f

uplink pwr: 1.24

rate: 256 kb/s

C: -28.6

No: -99.6

C/No = 71.0

BER: 0

$E_b/N_0$ : 17.0 (calculated)

### ***Appendix 3: Typical AeroSAPIENT DC-8 Aircraft Test Results***

December 11, 2000

location: Tinker AFB (in flight)

ant mode: INS

satellite: GE-2

Notes: GE-2 (85° W) Mobile K16 H, Fixed K14 H

*flight test*

transmit pol offset angle = 30°

*mobile to fixed*

time: 12:40 pm

m:f xpndr: K16H

UL freq: 14320

DL freq: 12020

user data rate: 256

Viterbi: 0.5

R-S: 0.9 (255/235)

C: -35.4

No: -101.9 C/No: 66.5

Eb/No: 12.5 (calculated) BER: 8 E-3

*fixed to mobile*

time: 12:50 pm

f:m xpndr: K14H

UL freq: 14280

DL freq: 11980

user data rate: 2180

Viterbi: 0.5

R-S: 0.9 (255/235)

C: -51.2

No: -129.5 C/No: 78.3

Eb/No: 14.1

BER: 2 E-6



#### ***Appendix 4: Typical ARIES 757 Aircraft Test Results***

April 3, 2002                      location: 36.566 N -77.319W, SW of Emporia, VA

ant mode: INS                      satellite: AMC-2

Notes: AMC-2 (85° W) Mobile K16 H, Fixed K12 H

pre-takeoff at LaRC

transmit pol offset angle = 103°              pwr meter = 2.0 dBm;  
Fixed uplink power = 11 W

measured M->F frequency: 70.00074 MHz

<i>fixed to mobile</i>	time: 1:06 pm	
f:m xpndr: K12H	UL freq: 14240	DL freq: 11940
user data rate: 2048	Viterbi: 0.5	R-S: 0.9 (255/235)
C: -52.2	No: -130.0	C/No: 77.8
Eb/No: 14.6	BER: 0	

<i>mobile to fixed</i>	time: 1:06 pm	
m:f xpndr: K16H	UL freq: 14320	DL freq: 12020
user data rate: 256	Viterbi: 0.5	R-S: none
C: -34.3	No: -101.0	C/No: 66.7
Eb/No: 12.7 (calculated)	BER: 0	



## Appendix 5: Typical Link Budget

Title: GE5 aeronautical experiment (GE-5)

Fri Mar 10 09:21:29 2000

\_\_\_\_\_ mobile to satellite \_\_\_\_\_

mobile uplink frequency: 14.50 GHz  
mobile uplink EIRP: 36.00 dBW  
mobile-to-sat range: 40000 km  
atmospheric attenuation: 0.30 dB  
pointing loss: 0.30 dB  
satellite GT: 4.00 dB/K

mobile-to-sat uplink C/No: 60.29 dB\*Hz

\_\_\_\_\_ satellite to fixed \_\_\_\_\_

flux density at satellite: -127.63 dBW/m<sup>2</sup>  
flux density for saturation: -88.00 dBW/m<sup>2</sup>  
difference: 39.63 dB

saturated satellite EIRP: 46.00 dBW  
sat-to-fixed frequency: 12.20 GHz  
sat-to-fixed range: 40000 km  
atmospheric attenuation: 0.30 dB  
pointing loss: 0.30 dB  
fixed station GT: 34.00 dB/K

flux density at fixed station: -117.63 dBW/m<sup>2</sup>  
base sat-to-fixed downlink C/No: 101.79 dB\*Hz

adjusted sat-to-fixed downlink C/No: 62.16 dB\*Hz

\_\_\_\_\_ composite \_\_\_\_\_

composite C/No: 58.11 dB\*Hz

data rate: 64.00 kb/s  
convolutional code rate: 0.50  
block code rate: 0.90  
modem bit rate: 142.22 kb/s

composite Eb/No: 6.58 dB  
required Eb/No: 5.50 dB  
downlink margin: 1.08 dB  
uplink margin: 3.26 dB

\_\_\_\_\_ fixed to satellite \_\_\_\_\_

fixed uplink frequency: 14.50 GHz  
fixed uplink EIRP: 80.00 dBW  
fixed-to-sat range: 40000 km  
atmospheric attenuation: 0.30 dB  
pointing loss: 0.30 dB  
satellite GT: 2.00 dB/K

fixed-to-sat uplink C/No: 102.29 dB\*Hz

\_\_\_\_\_ satellite to mobile \_\_\_\_\_

flux density at satellite: -83.63 dBW/m<sup>2</sup>  
flux density for saturation: -88.00 dBW/m<sup>2</sup>  
difference: -4.37 dB

saturated satellite EIRP: 46.00 dBW  
sat-to-mobile frequency: 12.20 GHz  
sat-to-mobile range: 40000 km  
atmospheric attenuation: 0.30 dB  
pointing loss: 0.30 dB  
mobile station GT: 12.00 dB/K

flux density at mobile station: -117.63 dBW/m<sup>2</sup>  
base mobile-to-sat downlink C/No: 79.79 dB\*Hz

adjusted sat-to-fixed downlink C/No: 79.79 dB\*Hz

\_\_\_\_\_ composite \_\_\_\_\_

composite C/No: 79.77 dB\*Hz

data rate: 1544.00 kb/s  
convolutional code rate: 0.50  
block code rate: 0.90  
modem bit rate: 3431.11 kb/s

composite Eb/No: 14.41 dB  
required Eb/No: 6.50 dB  
downlink margin: 7.91 dB  
uplink margin: 30.44 dB



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